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BEHAVIOR AND TEMPERATURE IN RHESUS MONKEYS EXPOSED TO LOW LEVEL MICROWAVE IRRADIATION

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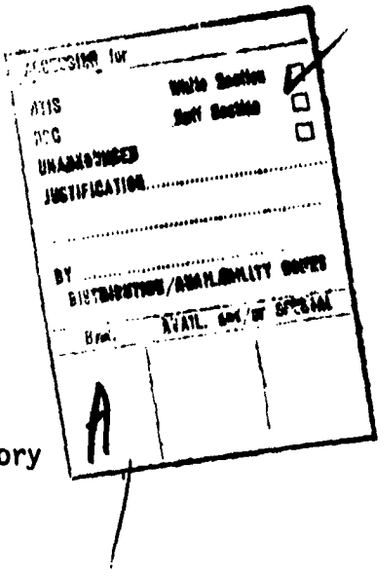

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SUMMARY PAGE

THE PROBLEM

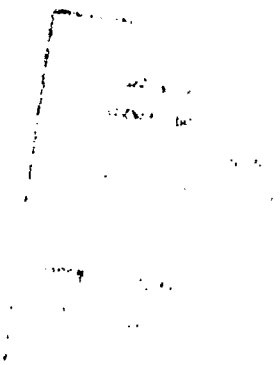
Microwaves are employed throughout the Navy in communications and weapons systems. Contemporary research has shown that the power densities and frequencies used might have biological effects. Because of these potentially biological effects, man is not the most appropriate subject; hence, investigations using monkeys, a biologically similar animal, should provide information somewhat applicable to man.

FINDINGS

Vigilance behavior in rhesus monkeys was not noticeably affected at power densities from 4 to 62 mW/cm^2, but at 72 mW/cm^2 a dramatic decrement in performance occurred. Colonic temperature increase appeared to be a logarithmic function of power density from 16 to 72 mW/cm^2, whereas no such relationship was seen with behavior. The animals adapted to the microwaves in both behavioral and thermal measures, and thermal equilibrium was obtained within an hour except at 72 mW/cm^2.

ACKNOWLEDGMENTS

The assistance of C. S. Ezell in conducting this study, and Dr. V. R. Reno and T. A. Griner in establishing the microwave environment is greatly appreciated. The assistance of Ms. M. Kelly in data collection and typing is also greatly appreciated.



INTRODUCTION

In the recent surge of research on the biological effects of microwaves few studies have investigated behavioral changes in monkeys. Most investigations have traditionally been concerned with effects on rats, cats and dogs. It is probably true that conclusions from such experiments are less applicable to man than are conclusions from experiments utilizing non-human primates. Research has shown that the rhesus has a distribution of temperature sensitivity over its body similar to that of man whereas rats, cats and dogs do not (5).

One of the earliest microwave studies on primates (1) found that rhesus monkeys became initially agitated, followed by drowsiness, then immobility when their heads were exposed to relatively high levels of microwaves. A later study (2) discovered that lower levels of microwaves, integral dose rates less than 10 W, at similar frequencies (383-MHz) had no behavioral effects on rhesus monkeys whose heads were irradiated. However, with 120 minute exposures and integral dose rates above 15 W, operant behavior was inhibited and the syndrome of agitation, drowsiness, and immobility was repeated.

Low level microwaves at 2450 MHz can be detected by the rhesus as reported by Young, Middleton and Curran (10). These investigators used whole body irradiation pulsed at 10 Hz and an average power density of 2 mW/cm^2 (peak power 4.5 W/cm^2). Although the monkeys could detect the microwaves, no other behavioral effects of the irradiation were reported. Galloway (4) also used 2450 MHz frequencies and generally found no behavioral influence on an operant task with levels less than 20 W. However, the latter study used a diathermy applicator applied to the rhesus head, and, quite often, convulsions occurred before behavioral disruption was seen. Generally, highly controlled performance, such as on an operant task, is seldom disrupted by subtle environmental stimuli unless reinforcement is contingent on a change in behavior relevant to that stimulus. For example, McAfee reported at the 1975 URSI meeting in Boulder that rhesus responding on an operant task for food were not perturbed behaviorally by a 9.3 GHz field at 350-450 mW/cm^2 when their heads were exposed for 15 minutes.

The ability of the rhesus to detect low levels of microwaves, but not have its performance disrupted until high power densities are presented, is not at all unusual in regards to other portions of the electromagnetic frequency spectrum. What would be highly interesting is to discover the aspects of the irradiation that are disturbing to the monkey. Perhaps it is only when the animal's body temperature is sufficiently raised that behavior changes.

The Baldwin, et al. (1) study reported rectal temperature increases averaging 2.5^{o}C and temperatures of 42^{o}C were occasionally obtained. However, no concurrent behavioral measures were recorded. The purpose of the present investigation was to determine the necessary power density to increase colonic temperature in the rhesus, and the relationship between the increases and a highly controlled operant behavior. Power levels were confined to

those of a sub-lethal nature. A vigilance task was chosen so as to reflect changes in the monkeys attentive behavior.

METHOD

SUBJECTS

Five male rhesus, Macaca mulatta, weighing approximately 4 kg at the beginning of the study were subjects in the first series of experiments. Three of these monkeys, 302, 626, and 560, were subjects in the second series and their respective mean weights during exposure were 4.5, 4.8, and 5.2 kg. All animals were food deprived and generally worked at weights between 90 and 100 percent of their free feeding weights.

APPARATUS

The 2450 MHz microwave source was a Holaday magnetron unit, Model HT-1200 with 120 Hz amplitude modulation. Initially, a collimated, vertically polarized beam from a parabolic reflector was used to irradiate the animal. Later a standard gain horn directly illuminated the animal exposure area. A block diagram illustrating the arrangement is provided in Figure 1.

Field measurements were obtained with both a Narda Field Sensor, Model 8316, and its probe, Model 8323, and a sensor obtained from the National Bureau of Standards, Model EDM-1-C2.

A monkey in a styrofoam restraint chair (8) was placed in the far field on the center of a stage within a large anechoic room described in a previous report (7). After determining the space occupied by the animal, power density measurements were made without the monkey in the chair at three planes--head, chest and abdomen. The measurements were obtained at 5 points on each of the three planes and the mean for the head was chosen as the reference for all of the power densities referred to in this study. Table 1 contains examples of the distribution as a function of power density. P Reflector refers to the distribution with the parabolic reflector and S G Horn refers to the distribution with the standard gain horn. The initial set of SGH data is an example of the relative distribution at levels from 16 to 62 mW/cm^2. The second SGH measurements were obtained when 72 mW/cm^2 was required and the chair moved nearer to the horn. Both SGH measurements were in the far field. The table shows that regardless of density, the head plane always had the maximum level.

Room temperature generally varied from 21°C to 24°C and relative humidity averaged 70%. Humidity typically decreased from morning to afternoon runs approximately 15%. Room temperature varied with the building air which was exchanged via ducts into the room approximately 1000 ft^3 per minute. No relationships were found between room temperature or humidity and behavior in this study.

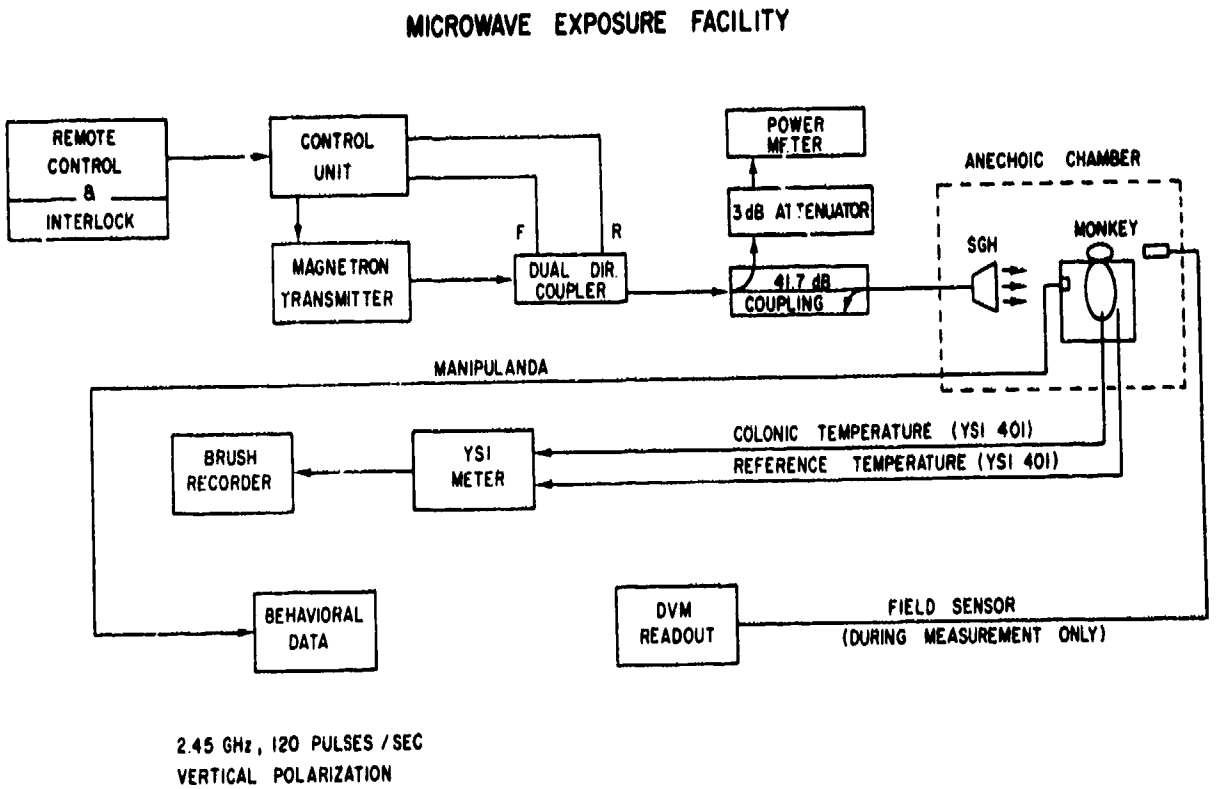


Figure 1

Diagram of the microwave exposure facility. The anechoic chamber is open at the front so that a large parabolic reflector can also be used.

Table I

E-Field Measurements Without The Monkey

Plane of Measurement	Field Intensity mW/cm^2		
	P Reflector	S G Horn	
Head	.288	36	72.6
Chest	.108	24.4	62.
Abdomen	.174	31.2	54.

Colonic temperature was obtained in the second series of experiments by inserting Yellow Spring Instruments' rectal probes, number 401, approximately 8 cm into the colon of the rhesus. An identical reference probe was located in the same orientation 15 cm to the left rear of the rectal probe. Potentially, the orientation of the probes would allow the maximal E field interaction. The probes were calibrated and tests made to determine interactions with the microwave when the probes were in their respective chair locations. No temperature rise due to irradiation occurred, but E field distribution was minimally altered with a decrease in power density of 10% at 2 cm distance in front of a probe, an increase of 3% at 4 cm, and an increase of 2% at 8 cm.

PROCEDURE

The monkeys were first trained in Plexiglas chairs for 70 sessions to operate two levers for Purina Monkey Chow pellets dropped into a recess in front of their mouths. At all times a white masking noise of approximately 79 dB was present. The task required the monkey to press a 5 cm Teflon lever directly in front of the animal's right arm. This response produced either a 1070 Hz, 85 dB tone or a 2740 Hz, 82 dB tone. The lower frequency tone remained on for 0.5 seconds and signaled the absence of food. The higher frequency tone remained on until a response on a similar lever in front of the monkey's left arm was made. A left lever response delivered a food pellet and extinguished the high tone. Food was made available on a variable interval 30 second (VI 30 sec) schedule during one hour sessions. In two hour sessions food was available on a variable interval 60 second (VI 60 sec) schedule. These schedules varied the time between food availability, but on the average it occurred at the designated intervals. This meant that if the animal pressed the right lever he would hear the high tone on the average of once a minute during a 2 hour session. All other right responses produced the low tone signaling the nonavailability of food. A left lever response during the high tone produced food. At other times left responses caused

a 10 second period during which right responses only produced the low tone. The latter condition inhibited extraneous left lever responses. The complete task has been referred to as a vigilance or observing response task.

After stable behavior was established, and following 122 sessions on the VI 30 sec schedule, microwaves were introduced. Following the one hour sessions, 18 additional sessions were required to stabilize behavior on the VI 60 sec schedules and two hour sessions. The experiment was interrupted at various times to install new equipment, employ temperature probes, and rearrange the chair nearer the horn. Table II summarizes the overall procedure. Asterisks in Table II indicate when these interruptions occurred. Although there is an orderly progression in the table, conditions were counterbalanced between 32 and 62 mW/cm^2 exposures.

Table II

Procedures and Conditions of Microwave Exposure

Power Density (mW/cm^2)	Subjects /probe	Session Length (min)	Exposure Duration (min)	Sessions Exp	Sessions Con
4 (PRF 1 Hz)	5	60	30	2	2
16 (PRF 1 Hz)	5	60	30	2	2
4	5	60	30	3	2
16	5	60	30	3	2
16*	3/1	120	60	4	7
16	3/1	120	120	3	4
32*	3/2	120	60	2-3	3-5
42	3/2	120	60	1-3	3-5
52	3/2	120	60	5-6	3-5
62	3/2	120	60	3	3-5
32*	3/3	120	60	1	6-7
42	3/3	120	60	2	6-7
52	3/3	120	60	2	6-7
62	3/3	120	60	1	6-7
72	3/3	120	60	5	6

The monkeys were first exposed to power densities of 4 and 16 mW/cm^2 in the beam from the parabolic reflector which was pulsed with relay closures at 1 Hz and a pulse duration of .1 seconds. The discrete 1 Hz pulses were superimposed over the characteristic 120 Hz modulation of the magnetron. No temperature probes were used at this time. Next, 4 and 16 mW/cm^2 exposures occurred without the superimposed 1 Hz pulses. All of these sessions lasted one hour and exposures were of 30 minute durations. As seen in Table II the rest of the study employed 2 hour sessions and except for the 2 hour exposures at 16 mW/cm^2 all other exposures lasted one hour. At 16 mW/cm^2 body temperature was only obtained in one animal while three animals provided temperature measurements at all higher levels. The exposures above 16 mW/cm^2 were with the SGH directed at the animal.

The experiment was conducted 5 days a week. The animals were transported from the colony building to the microwave facility approximately 15 minutes prior to being placed in the restraint chair. Five minutes were required to restrain the monkey, insert the rectal probe and activate the equipment. In general, the first and last quarters of a session were control periods whereas the middle portion was when the microwave field was automatically turned on.

Animals were given standard physical examinations including ophthalmoscopy before and after each series of exposures.

RESULTS AND DISCUSSION

No clinically detectable abnormalities in blood chemistry or eye structures were noted in any of the monkeys following microwave exposure.

All of the animals were relatively docile by the time microwave sessions began and only one man was needed to chair a monkey and insert the temperature probe. No overt signs of emotional stress such as excessive urination or defecation were observed to be a consequence of restraint. One animal consistently defecated during restraint while the others tended to defecate during transport.

Measures of observing response rate, overall rate on the right lever, and detection response rate, rate on the left lever, were obtained. In addition, reinforcement reaction time, latency to respond on left lever during a high tone, and post reinforcement pause time were recorded. No differences in these various measures occurred when the 5 monkeys were exposed to 4 and 16 mW/cm^2 for 30 minutes. The results were the same regardless of whether or not the 120 Hz modulation was pulsed. No effects, either during or following exposure, were detectable at these levels and duration, hence longer duration exposures at 16 mW/cm^2 were conducted.

One and two hour exposures, rows 5 and 6 of Table II, to 16 mW/cm^2 had no differential effect on behavior in all three animals, or temperature in monkey 302. The different duration data were therefore combined for the remaining calculations and figures.

When three monkeys were exposed to greater than 16 mW/cm^2 densities definite temperature increases occurred as seen in Figure 2. Power density is indicated on the abscissa and colonic temperature increase is shown on the ordinate as a log scale. The single point at 16 represents the mean temperature increase for monkey 302 during one and two hour exposures. The control points represent increases during the comparable portion of control sessions. The power density refers to that measured at the level of the monkey's head and these increases occurred during a 60 minute exposure period.

There is in general a logarithmic relationship between colonic temperature increase and incident irradiation as shown in Figure 2. However, individual animals differed. Monkey 626 had similar increases at 32, 42, and 52 mW/cm^2 whereas 560 had a more logarithmic increase. The temperature of 302 at 16 mW/cm^2 did not differ from control periods and irregularly increased with increases in power density.

Regardless of the regularity seen in the temperature increase, behavior was consistently affected only at 72 mW/cm^2. Typically the monkey would accelerate its moving around in the chair after about 20 minutes of exposure as if somewhat agitated. After about 30 minutes it would take short naps and increased its sleep duration, sometimes seeming to be in a deep sleep. When the irradiation was turned off, about 10 minutes elapsed before the animal became active again.

The data in Figure 2 are averages, and individual daily records varied substantially. Some control days even had decreases of as much as .3^{o}C. A plateau was generally reached by 30 minutes into exposure at 32 mW/cm^2, in 30-50 minutes at 42 and 52 mW/cm^2, and in 50-60 minutes at 62 mW/cm^2. The animals were still increasing temperature at 60 minutes during exposure to 72 mW/cm^2. Michaelson (6) found similar plateaus and an attainment of thermal equilibrium in unrestrained dogs exposed to 165 mW/cm^2, 2790 MHz fields during one hour. Further exposure produced a breakdown in thermal equilibrium and then death. On the other hand, when Michaelson exposed dogs to 100 mW/cm^2, critical rectal temperatures were not reached.

This observation, that colonic temperature was increasing to dangerous levels after an hour's exposure at 72 mW/cm^2, actually precluded the exploration of effects at higher power densities. As power density was raised, the animals tended to show some equilibration in their temperature similar to that observed in dogs (6), as if a compensatory mechanism was activated. Examples of these temperature variations are seen in Figure 3 for monkey 626. These records are of consecutive daily sessions and illustrate a number of idiosyncracies in this particular animal. Temperature increases on the second and third exposure to 72 mW/cm^2 (C and D in Figure 3) were not as great as during the first exposure (B) which produced a body temperature greater than 42^{o}C. Record D shows a drastic drop in temperature after about 10 minutes of exposure. This decrease, and perhaps much of the variation in the other records may have been due to the probe's position in the colon and bowel movement of the animal. 626 consistently defecated during a session and was one of the most active animals even when not irradiated.

Although body temperature was regularly affected by microwaves, behavior in general was only influenced at the highest power density. Observing

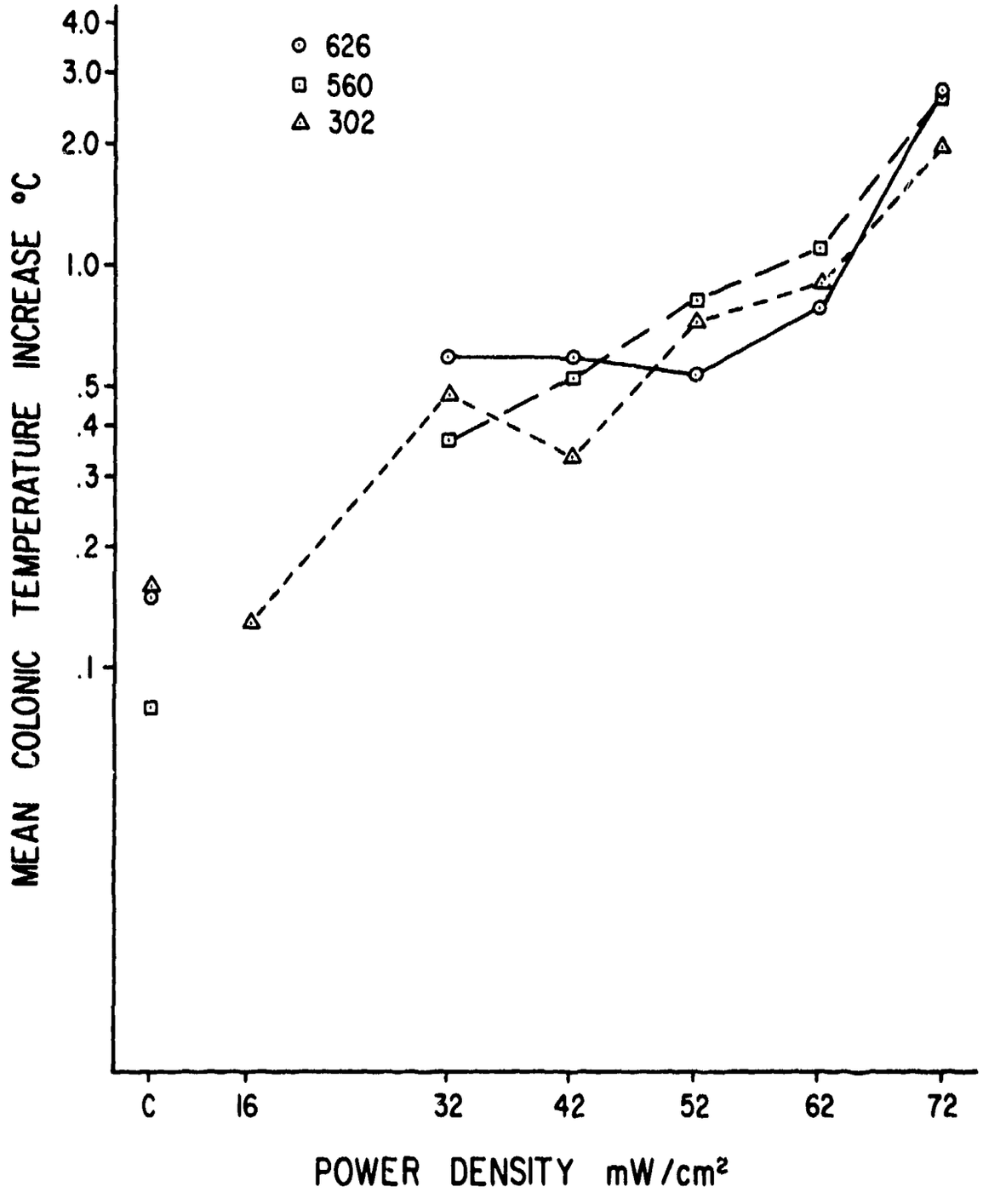


Figure 2

The average rectal temperature increase as a function of power density when three rhesus were exposed for 60 minutes. The temperature scale is logarithmic. C refers to temperatures averaged over similar 60 minute periods during all non-exposure sessions. The individual animals are indicated by symbols shown at the top of the graph.

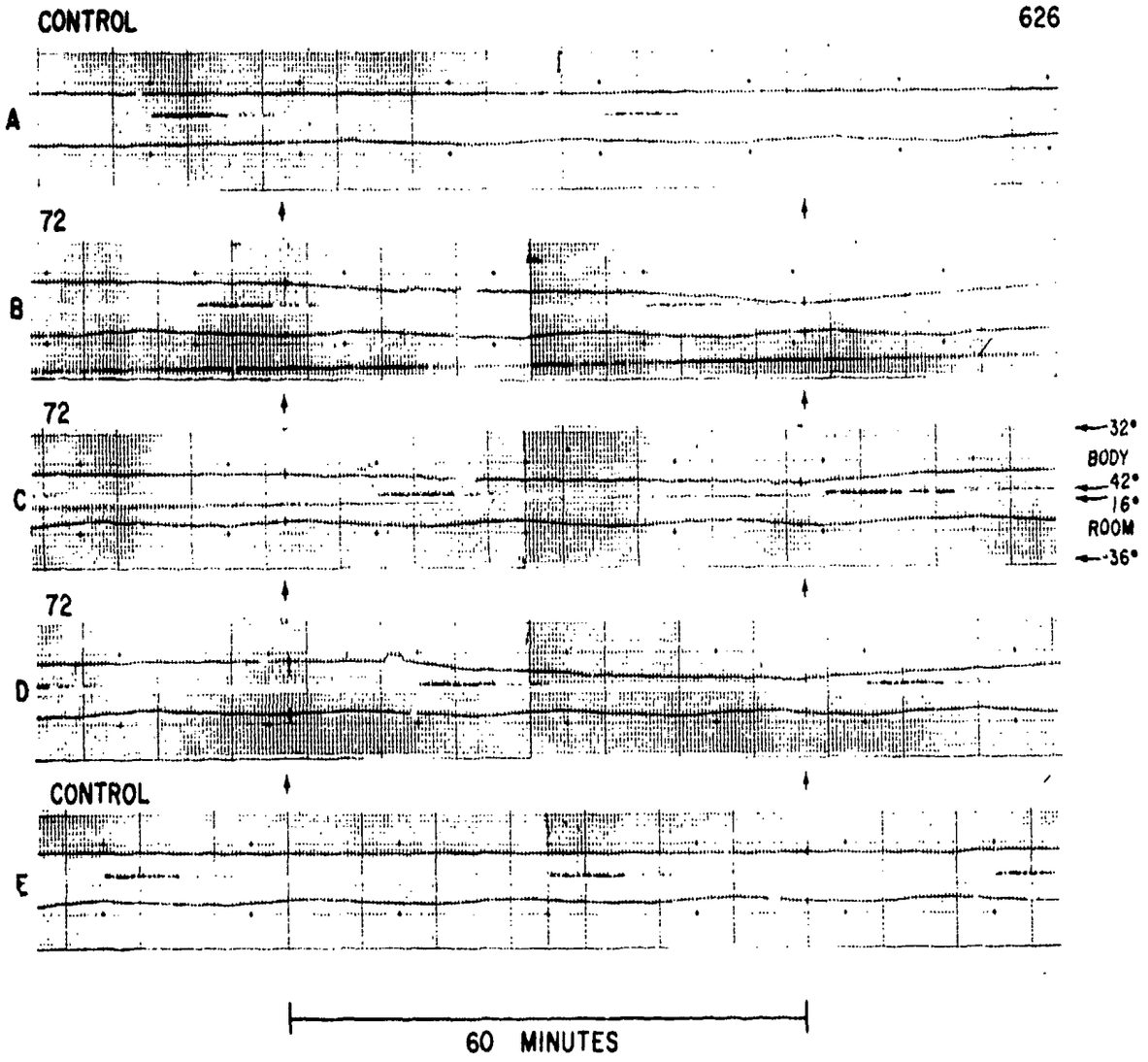


Figure 3

Body and room temperature records of 626 during five consecutive 2 hour sessions beginning at A. Arrows denote the 60 minute period of 72 mW/cm^2 irradiation except during the control sessions. Sessions start at the left of the figure. The label on the right indicates the temperature scale. Colonic temperature is shown on the top line in each pair of records. Vertical marks on the recordings were purposely made by the experimenter.

response rate for two monkeys was no different from control periods until 72 mW/cm^2 was reached at which time a dramatic decrease occurred. One monkey, 626, reduced his rate at 62 mW/cm^2 also. A summary is provided in Figure 4 which compares the middle periods of exposure sessions with control sessions as a function of power density. Points falling on the 100 percent line indicate exposure and control periods were the same. Points below the line mean that the exposure periods contained lower response rates than comparable control periods.

Other aspects of vigilance behavior were similarly affected. For example, the latency to make a detection response increased greatly in all three animals at 72 mW/cm^2 as shown in Figure 5. The same behavior was not changed at lower levels with 626 although 560 showed a gradual slowing as the densities increased. The other monkey, 302, had increased reaction times at 52 and 62 mW/cm^2 also.

Although post reinforcement pauses also increased during exposure at 72 mW/cm^2, consistent relationships at the lower levels were not evident and; in general, levels from 16-62 mW/cm^2 did not influence this behavior in any of the three monkeys.

The rate of responding on the left lever, detection response rate, was highly variable; and, while two animals showed no obvious differences between control and exposure periods, the other animal, 302, responded at higher rates during 32, 42, and 52 mW/cm^2, and at lower rates during 62 and 72 mW/cm^2.

Figure 6 shows typical cumulative records of right lever responding during two hour sessions for monkey 302. The records, as indicated on the left, cover 16 to 72 mW/cm^2 exposures and a control session conducted at the end of the experiment. The arrows denote beginning and end of the microwave irradiation. The hash marks on the diagonal lines indicate food delivery while the horizontal line denotes the food available signal when it is deflected. Session records begin at the left and responses drive the pen upward. As is seen here, no obvious perturbations existed until 72 mW/cm^2 was introduced. At that time a gradual decrement in rate occurred and latency to respond for food on the left lever increased. Within 5 to 10 minutes following the removal of the field, observing responses began again and gradually approached normal rates near the end of the session.

In two of the animals, the initial presentation of 52 and 62 mW/cm^2 fields was accompanied by a pause in responding when the fields were removed. On further applications this effect was not seen and it may have been an artifact. No other phenomena were observed at lower levels when the microwaves were turned off.

The effect of 72 mW/cm^2 power density was very consistent and in every application produced the same phenomena. Figure 7 shows five consecutive days of cumulative recordings for monkey 560. The first and fifth sessions were control periods and all are complete 2 hour sessions. Arrows indicate the one hour period when the microwaves were present. The behavior was not affected during the first 20 minutes of exposure and then gradually responding decreased. With further exposures the behavior tended to be less

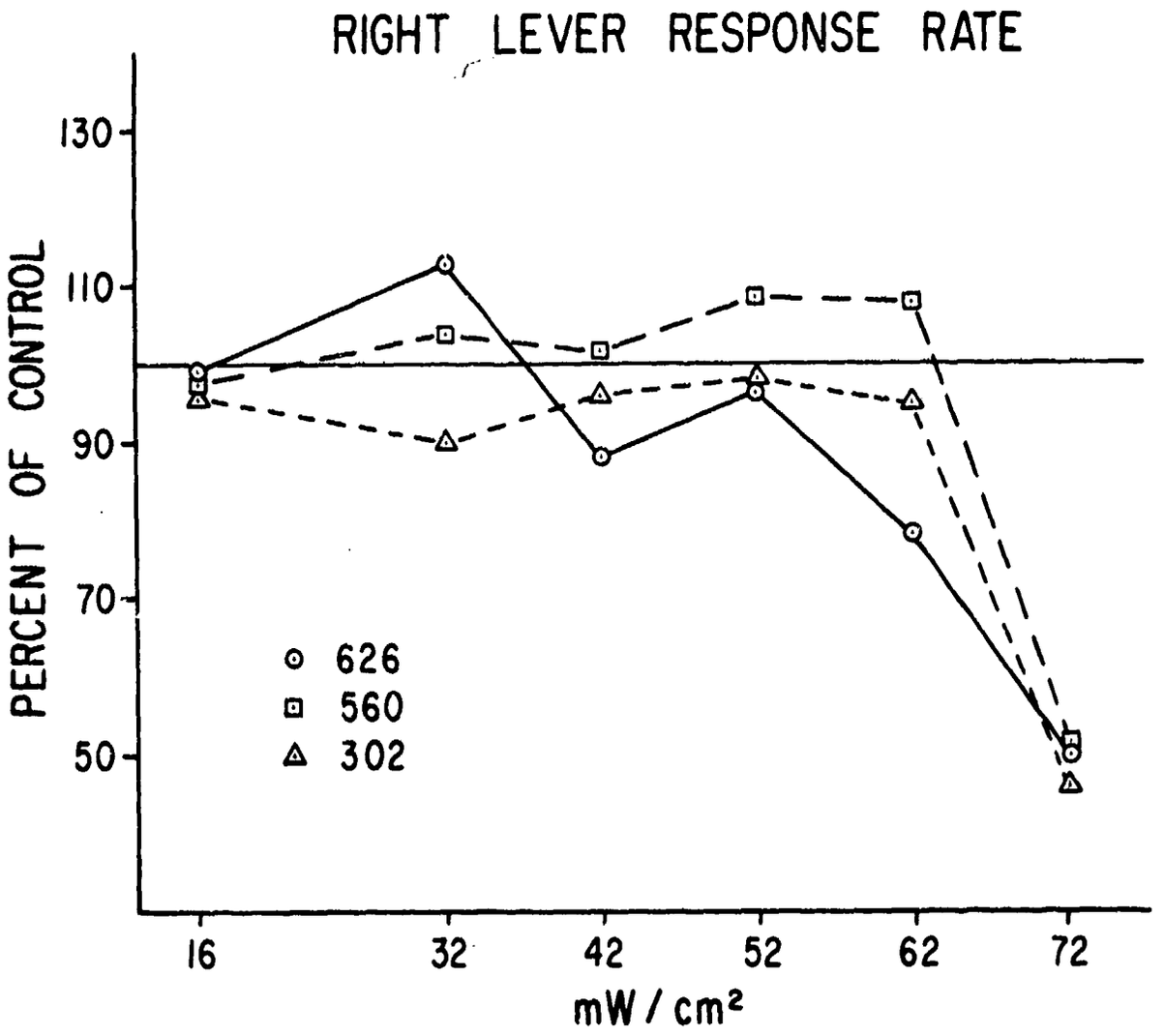


Figure 4

The ratio of response rate on the right lever during exposure sessions to control sessions. The line denotes the 100 percent ratio or no-difference ratio. The symbols refer to three monkeys as identified in the lower left corner.

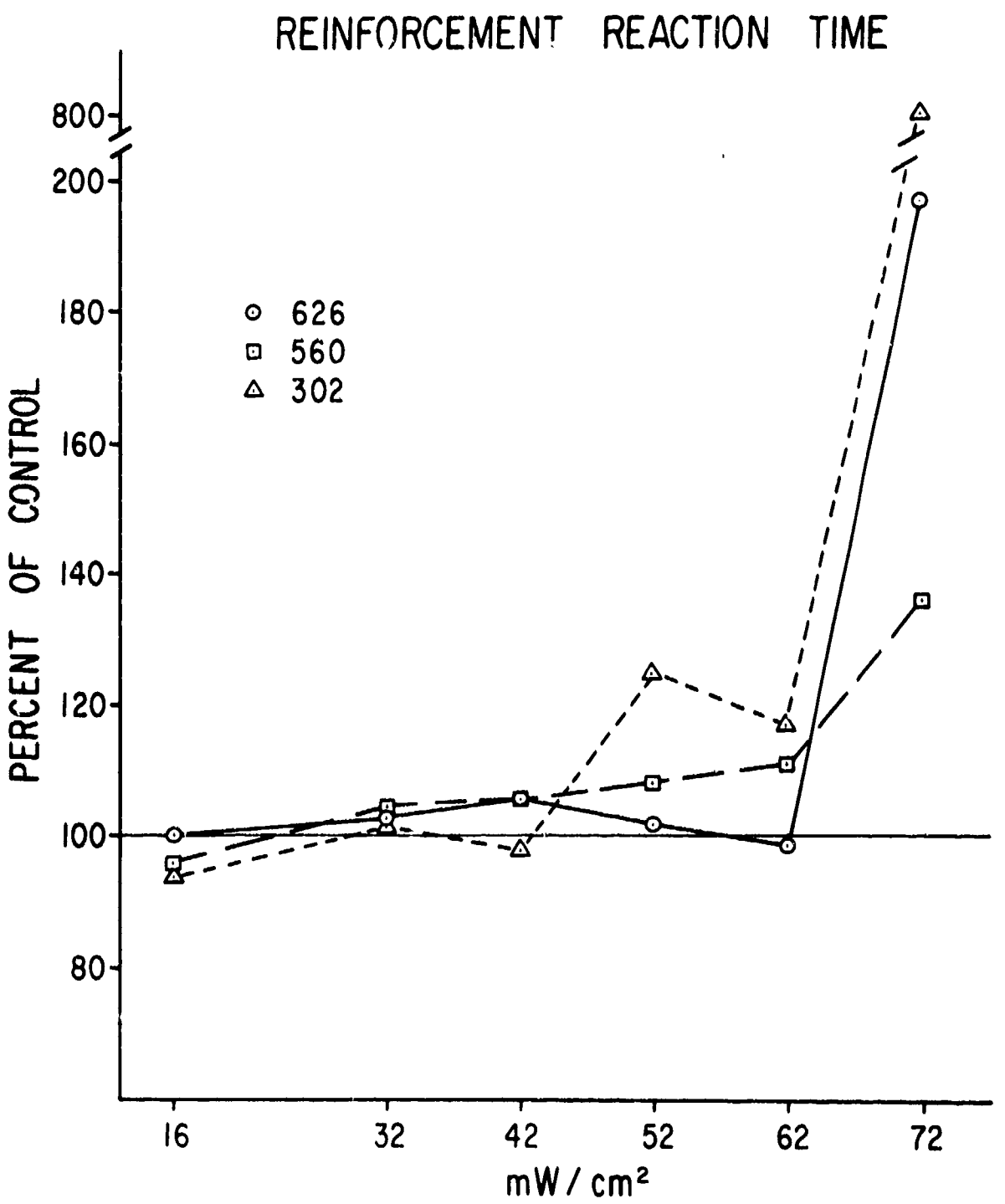


Figure 5

The ratio of the latency to respond on the left lever when food is signaled in exposure compared with control sessions. The symbols and lines are the same as in Figure 4.

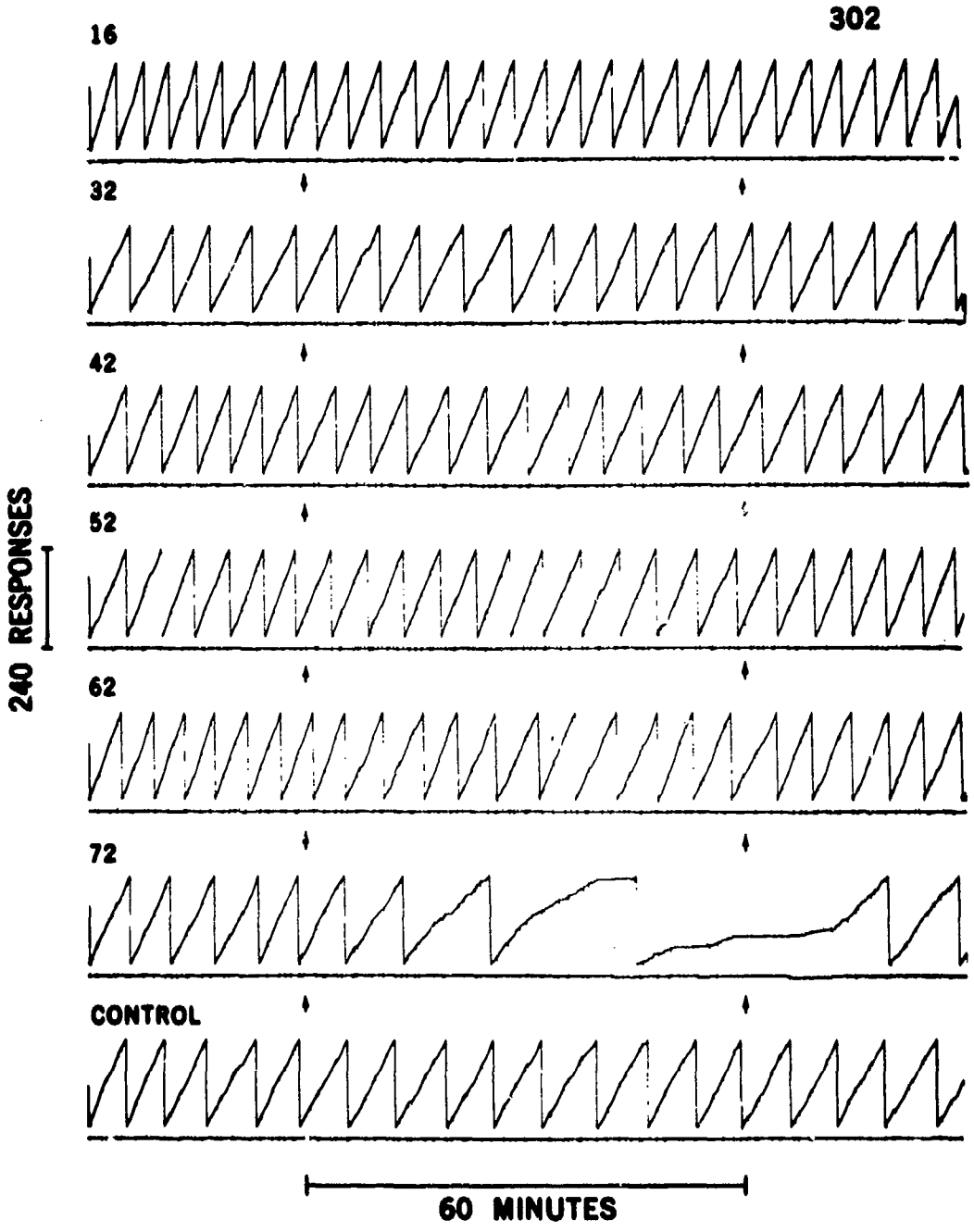


Figure 6

Cumulative records of right lever responding as a function of the various power densities indicated on the left side. These 2 hour records are typical of 302's behavior, but the other two monkeys were essentially the same. Arrows refer to start and end of the radiation. Deflections on the horizontal lines indicate food availability and hash marks on the slanted lines denote food delivered. Each traverse of a record was 240 responses and the response pen reset to the bottom of the record at this time or where the session ended.

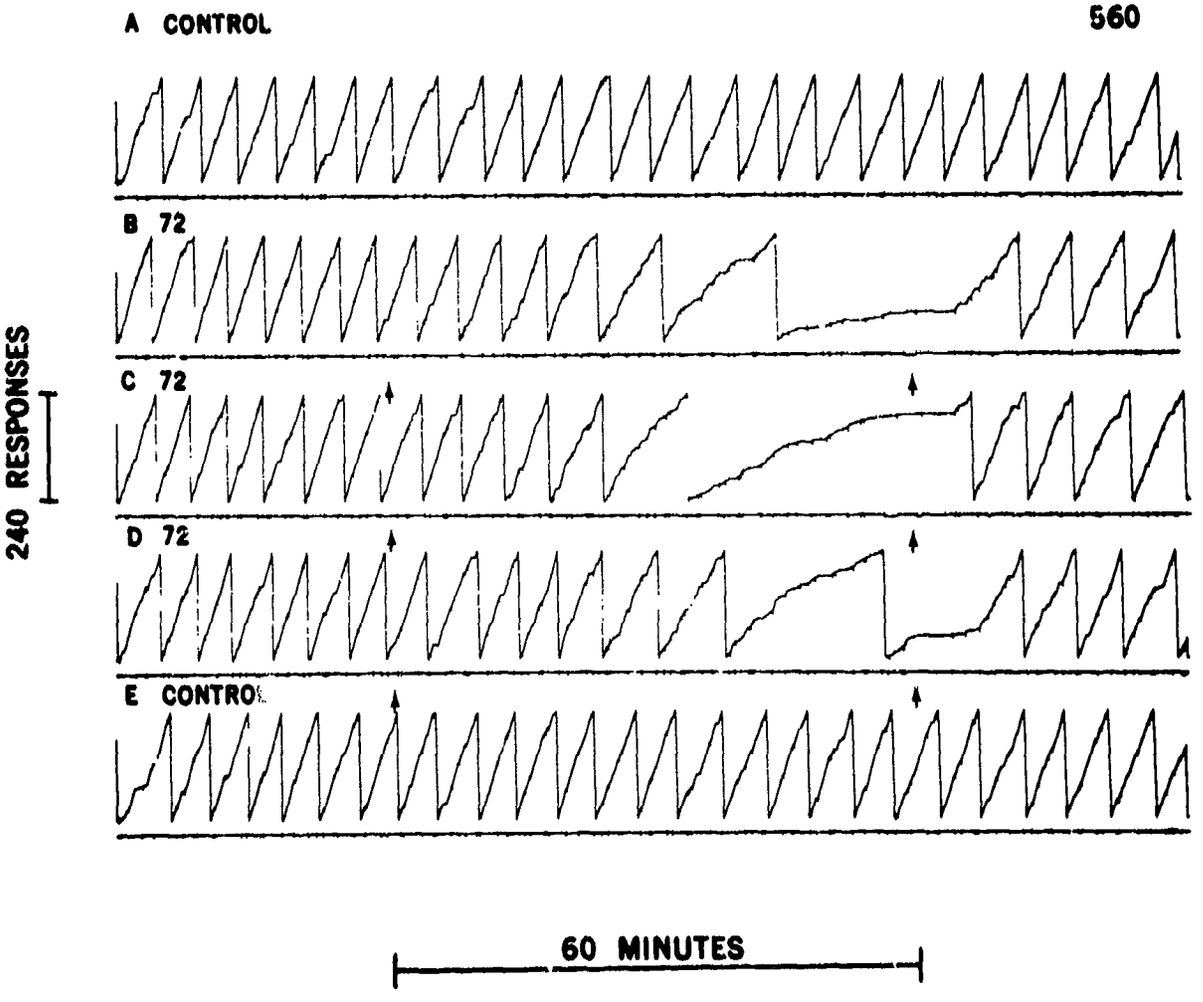


Figure 7

Cumulative records of right lever responding for monkey 560 during 5 consecutive 2 hour sessions beginning with A Control and ending at E Control. Arrows denote when the 72 mW/cm^2 field was turned on and off.

disrupted. This adaptation was seen in all three animals in both behavior and temperature measurements. Following the removal of the microwaves, approximately 5 to 10 minutes elapsed before responding began.

A simultaneous comparison of behavior and temperature can be made in Figure 8 which contains records of monkey 302 during the first session of exposure to 72 mW/cm^2 power density. The microwaves were presented at 30 minutes into the session and after 57 minutes the field was turned off when the monkey failed to respond to the food available signal. The feeder was then manually actuated and the animal ate the food pellet, but approximately 25 minutes elapsed before he renewed responding. This animal stopped responding when a 41^{o}C temperature was reached. The other two monkeys were not affected this drastically on their initial exposure to 72 mW/cm^2. The increase in room temperature seen in this figure during irradiation was a coincidence due to the building air conditioner cycling.

These results confirm and expand the findings reported in the few published studies on microwaves and monkeys. A complex operant task can be sensitive to various levels of microwave radiation as measured by incident power density, and thresholds for behavioral effects in rhesus monkeys are probably between 50 and 70 mW/cm^2 during a 60 minute exposure. In addition, there is some attenuation of the effect with continued presentation of the microwaves. The attenuation can be observed in both behavior and body temperature.

The various observations made during this study, especially the subjective impression gained by watching the animals, suggest that the monkeys react to subtle body heating, then gradually succumb to this heat. When the microwave energy was removed and the heat could be more rapidly dissipated, it is as if a cooling stimulus appeared and behavior was further inhibited. Similar cooling following microwave exposure has also been observed in dogs (6). It may well be the case that studies in which subjects are first irradiated in one environment and then removed to another for behavioral assessment, produce results reflecting relatively greater reductions in body temperature instead of relatively greater power densities. That is, a monkey irradiated at 32 mW/cm^2 increased its body temperature .5^{o}C. The same animal irradiated at 72 mW/cm^2 increased its temperature 2.0^{o}C. When the microwaves were removed the first time, the animal's temperature dropped .5^{o}C whereas the second time the decrement was 2.0^{o}C. The question is, "If behavior is measured during the recovery to baseline temperature, is it differentially affected by the level of temperature decrease?" For example, a recent experiment with rats (9) using low level irradiation found differential behavior related to various levels of power densities and frequencies. However, that particular study irradiated the rats for 30 minutes in an animal holder then placed the rats in a standard operant conditioning chamber for 60 minutes to measure behavior. Approximately 5-10 minutes elapsed from irradiation to behavioral assessment. Were the investigators actually observing a behavioral effect directly caused by microwaves, or were they seeing an effect caused by first, raising the temperature of the rats to different levels and then allowing them to cool? The present study avoided such confusion by measuring behavior while the animals were undergoing irradiation.

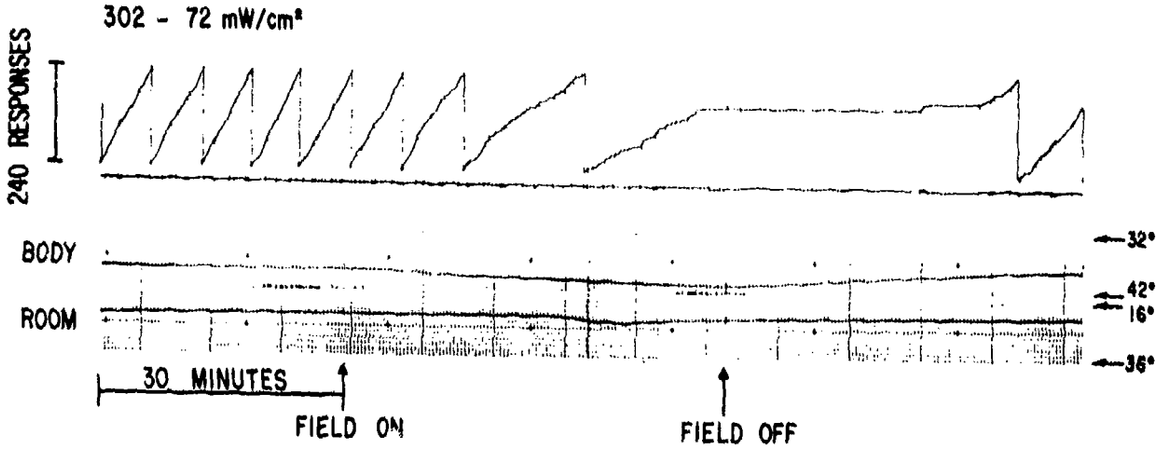


Figure 8

A complete session's records of temperature and right lever responding when monkey 302 was first exposed to 72 mW/cm^2 power density. The temperature scale is on the right and the top temperature recording is colonic temperature as indicated on the left.

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Rhesus monkeys

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Male rhesus monkeys, trained to respond on an auditory vigilance task, were exposed to vertically polarized 2450 MHz microwaves in an anechoic room. Power densities of 4, 16, 32, 42, 52, 62, and 72 mW/cm^2, and exposure times of 30, 60, and 120 minutes were used. The monkeys performed the vigilance task in a styrofoam restraint chair while irradiated from the front. Body temperature was monitored during exposure at all but the lowest power density. Vigilance performance was not affected until 72 mW/cm^2 illuminations occurred. Colonic temperature increase appeared to be a logarithmic function of power

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density from 16 to 72 mW/cm^2, whereas no such relationship was observed with behavioral indices. The animals showed adaptation to the microwaves in both behavioral and thermal measures, and thermal equilibrium was obtained except at 72 mW/cm^2

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